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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING CHARACTERISTICS OF A $\frac{1}{21}$ -SCALE MODEL

OF THE DOUGLAS AD-2W AIRPLANE

TED NO. NACA DE329

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of the Douglas AD-2W airplane which has a large radome installation. Spin tests were performed with a $\frac{1}{21}$-scale model simulating the normal gross weight of the airplane.

The results indicate that the AD-2W airplane will have satisfactory erect and inverted spin-recovery characteristics. A comparison of the results with those obtained for spin tests of a model of similar design, the Douglas XBT2D-1 airplane, showed that the radome installation on the subject model had little effect on the spin-recovery characteristics.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy free-spinning wind-tunnel tests have been performed in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of the Douglas AD-2W airplane. The AD-2W airplane is essentially the Douglas XBT2D-1 airplane, a model of which had previously been spin tested in the Langley 20-foot free-spinning tunnel (reference 1) plus a large bulbous appendage secured beneath the fuselage known as a "radome," a canopy extension, and a slightly increased rudder area. The radome is located beneath the fuselage between the engine cowl and the trailing edge of the wing as shown in figure 1. The weight and moments of inertia for the AD-2W have been increased over those of the XBT2D-1 and the center of gravity has been moved further rearward.

Erect and inverted spin and recovery tests were performed with the model simulating the normal gross-weight loading of the airplane for maximum and intermediate control deflections.

SYMBOLS

b	wing span, feet
S	wing area, square feet
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)
m	mass of airplane, slugs
ρ	air density, slugs per cubic foot
μ	relative density of airplane $\left(\mu = \frac{m}{\rho S b}\right)$
I_X, I_Y, I_Z	moments of inertia about X-, Y-, and Z-body axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
α	angle between thrust line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second

Ω full-scale angular velocity about spin axis, revolutions per second

σ helix angle, angle between flight path and vertical, degrees (For this model, the average absolute value of the helix angle was approximately 3.5°.)

β approximate angle of sideslip at center of gravity, degrees (Sideslip is inward when inner wing is down by an amount greater than the helix angle.)

APPARATUS AND METHODS

The model used for the current tests was the $\frac{1}{21}$-scale model of the XBT2D-1 airplane which had been used for the tests reported in reference 1. It was modified to represent in mass and dimensions a $\frac{1}{21}$-scale model of the AD-2W airplane. The canopy, however, was not altered inasmuch as it is generally believed from spin-tunnel experience that the effect of a canopy on the spin-recovery characteristics of an airplane is negligible. A photograph of the model as tested is shown as figure 2 and the dimensional characteristics are given in table I.

The model was ballasted to simulate dynamically the AD-2W airplane at an altitude of 15,000 feet ($\rho = 0.001496$ slug per cubic foot) and a remote-control mechanism was installed in the model to actuate the controls for recovery tests. Sufficient hinge moments were exerted on the rudder during recovery tests to ensure its full and rapid movement.

Wind Tunnel and Testing Technique

The model tests were performed in the Langley 20-foot free-spinning tunnel in a manner similar to that described in reference 1. The testing procedure and technique for obtaining and converting the data to full-scale values were the same as those used in reference 1.

PRECISION

The model test results presented herein are believed to be the true values given by the model within the following limits:

α, degrees	±1
ϕ, degrees	±2
V, percent	±5
Ω, percent	±2

Turns for recovery:

When obtained from film records	$\pm\frac{1}{4}$
When obtained visually	$\pm\frac{1}{2}$

The preceding limits may have been exceeded for certain spins in which it was difficult to handle the model in the tunnel because of the high rate of descent or because of the oscillatory nature of the spin.

Comparison between spin results of airplanes and their corresponding models (references 2 and 3) indicates that spin-tunnel results are not always in complete agreement with full-scale spin results. In general, the models spin at somewhat smaller angles of attack with higher rates of descent and with 5° to 10° more outward sideslip than their full-scale counterparts. The comparison made in reference 3 showed that approximately 80 percent of the model recovery tests predicted satisfactorily the corresponding airplane turns for recovery while 10 percent underestimated and 10 percent overestimated them.

Because of the impracticability of exact ballasting, the measured weight and mass distribution of the model varied from the true scaled-down values by the following amounts:

Weight, percent		0
Center-of-gravity location, percent $\bar{c}$		1 forward
Moments of inertia	I_X, percent	15 high
	I_Y, percent	22 high
	I_Z, percent	16 high

The limits of accuracy of the measurements of the mass characteristics are believed to be:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5

The controls were set with an accuracy of $\pm1^{\circ}$.

TEST CONDITIONS

The mass characteristics and inertia parameters for the normal gross-weight loading of the AD-2W airplane and for the equivalent loading tested on the model are listed on table II and plotted on figure 3. For comparison, the corresponding values for the XBT2D-1 airplane are also given. As discussed in reference 4, figure 3 can be used in predicting the relative effectiveness of the controls on the recovery characteristics of airplanes.

For the tests, the maximum control deflections used were:

Rudder, degrees . . . . 25 right, 25 left
Elevator, degrees . . . . 25 up, 15 down
Ailerons, degrees . . . . 12 up, 12 down

The intermediate control deflections used were:

Rudder deflected two-thirds, degrees . . . . $16\frac{2}{3}$
Elevator deflected two-thirds up, degrees . . . . $16\frac{2}{3}$
Ailerons deflected one-third, degrees . . . . 4 up, 4 down

The tail-damping power factor of the AD-2W airplane was calculated by the method described in reference 5.

For all tests reported herein, the landing flaps were neutral, the landing gear retracted, and the cockpit canopy closed.

RESULTS AND DISCUSSION

Erect Spins

The results of the spin tests simulating the AD-2W airplane in its normal gross-weight loading (loading 3 on table II and fig. 3) are presented on chart 1. The model data are presented in terms of the full-scale values for the airplane at a test altitude of 15,000 feet. The tests were performed for both right and left spins but only the results of the right spins, which yielded slightly conservative results, are presented. The results indicate that the spin-recovery characteristics of the AD-2W model are satisfactory. For the normal-control configuration for spinning, (elevator full up, ailerons neutral, and rudder full with the spin) the AD-2W model spun at a moderate attitude and recovered in 1 turn or less upon full rapid rudder reversal. For the "criterion" spin (elevator two-thirds up, ailerons one-third against the spin) recovery was effected in $1\frac{1}{4}$ turns when the rudder was reversed from full with the spin to only two-thirds against the spin. Aileron-against control settings were found to have a slightly adverse effect on the recovery characteristics, particularly when the elevator setting was neutral or down.

Comparison of the data on chart 1 with the results obtained on the XBT2D-1 model in its normal loading (loading 2 on table II and fig. 3) as presented in reference 1 shows generally good agreement between the results of the models. This comparison shows, therefore, that the radome installation of the AD-2W had very little effect on the spin and recovery characteristics of the airplane.

Inverted Spins

Brief inverted spin tests were performed on the model. These results, not presented in detail in this report, showed the model to have satisfactory inverted spin-recovery characteristics and the results were similar to those presented in reference 1.

Recommended Recovery Technique

On the basis of the test results the use of the following spin-recovery technique is recommended:

For erect spins, the stick should be held full back and laterally neutral. The rudder should be reversed fully and rapidly against the spin. When reversing the rudder, extreme care should be exercised to avoid entering a spin in the opposite direction after recovery. Approximately 1/2 turn after rudder reversal, the stick should be moved forward of neutral. In moving the stick forward, care should be exercised to avoid excessive rates of acceleration in the ensuing recovery dive.

For inverted spins, the rudder should be reversed rapidly against the spin and the stick should be neutralized (laterally and longitudinally).

CONCLUSIONS

On the basis of the results of free-spinning tests of a $\frac{1}{21}$-scale model of the Douglas AD-2W airplane and a comparison of these results with the results obtained for spin tests of a $\frac{1}{21}$-scale model of the Douglas XBT2D-1 airplane, the following conclusions regarding spin and recovery characteristics have been made:

1. The erect and inverted spin-recovery characteristics of the AD-2W airplane will be satisfactory.

2. The radome installation had very little effect on the spin and recovery characteristics of the airplane.

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5. Neihouse, Anshal I., Lichtenstein, Jacob H., and Pepoon, Philip W.: Tail-Design Requirements for Satisfactory Spin Recovery. NACA TN No. 1045, 1946.

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2. Douglas Aircraft Co., Inc., Drawings: AD-2W Radome.

3. Martinez, J. F.: Airplane Moments of Inertia, Model XAD-1W. Report no. E.S. 20964, Douglas Aircraft Co., Inc. Nov. 11, 1947.

TABLE I.– DIMENSIONAL CHARACTERISTICS OF THE AD-2W AIRPLANE

Length over-all, ft	39.64
Propeller diameter, ft	13.5
Propeller, number of blades	4
Wing:	
Span, ft	50.19
Area, sq ft	400.3
Section, root	NACA 2417
Section, tip	NACA 4413
Incidence:	
Root, deg	3.75
Tip, deg	0.25
Dihedral, deg	6
Mean aerodynamic chord ($\bar{c}$), in.	100.05
Leading edge of mean aerodynamic chord rearward of leading edge of wing, in.	14.125
Ailerons:	
Area aft of hinge line, sq ft	33.4
Hinge line to trailing edge (outboard tip), percent of chord	19.0
Span, percent of wing span	24.3
Horizontal tail surfaces:	
Total area, sq ft	86.97
Span, ft	19.83
Elevator area (aft of hinge line), sq ft	22.3
Distance from normal center of gravity to the elevator hinge line, ft	22.3
Section, modified	NACA 0012-64
Vertical tail surfaces:	
Offset, deg (leading edge to left)	3
Total area, sq ft	39.9
Total rudder area (aft of hinge line), sq ft	19.66
Distance from normal center of gravity to rudder hinge line, ft	23.6
Section	Modified NACA 0012 and 13
Tail-damping power factor	737×10^{-6}

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TABLE II.– MASS AND INERTIA CHARACTERISTICS FOR LOADING CONDITIONS OF THE DOUGLAS AD-2W AND XBT2D-1 AIRPLANES AND FOR THE LOADING TESTED ON THE $\frac{1}{21}$-SCALE MODEL OF THE AD-2W

[Model values given as corresponding full-scale values; moment-of-inertia values are about the center of gravity]

	Number	Loading	Weight (lb)	Airplane relative density, μ		Center-of-gravity location		Moments of inertia (slug-ft^2)			Inertia parameters		
				15,000 ft	Sea level	$x/\bar{c}$	$z/\bar{c}$	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
Airplane													
AD-2W	1	Normal gross weight	16,154	16.72	10.50	0.286	0.053	16,060	27,634	40,160	-92×10^{-4}	-99×10^{-4}	191×10^{-4}
XBT2D-1	2	Normal	15,558	16.07	10.11	.215	–.07	14,831	25,647	36,616	–90	–91	181
Model													
AD-2W	3	Normal gross weight	16,230	16.81	10.57	0.276	0.037	19,340	34,020	46,950	-116×10^{-4}	-102×10^{-4}	218×10^{-4}

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CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF THE $\frac{1}{21}$-SCALE MODEL OF THE DOUGLAS AD-2W AIRPLANE

[Normal gross weight loading (loading 3 on table II and figure 3); landing gear retracted; cockpit canopy closed; recovery attempted by rapid full rudder reversal except as otherwise indicated (recovery attempted from, and steady-spin data presented for, rudder-with spins); right erect spins]

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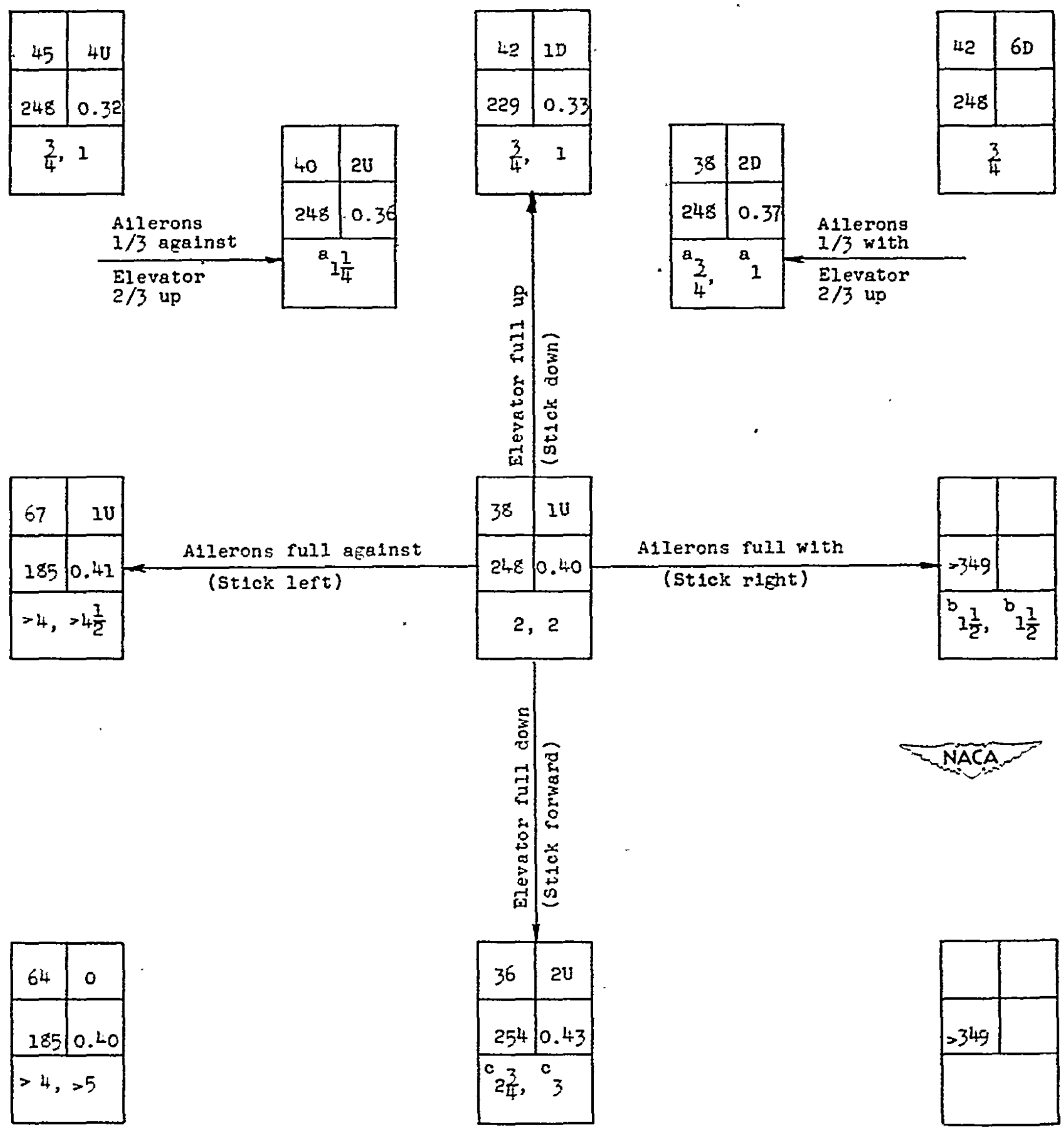
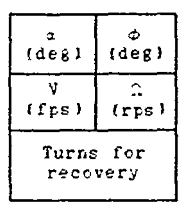


a Recovery attempted by reversing the rudder from full with to 2/3 against the spin.
b Recovery attempted before model reached its final spin attitude.
c Model recovers inverted.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down



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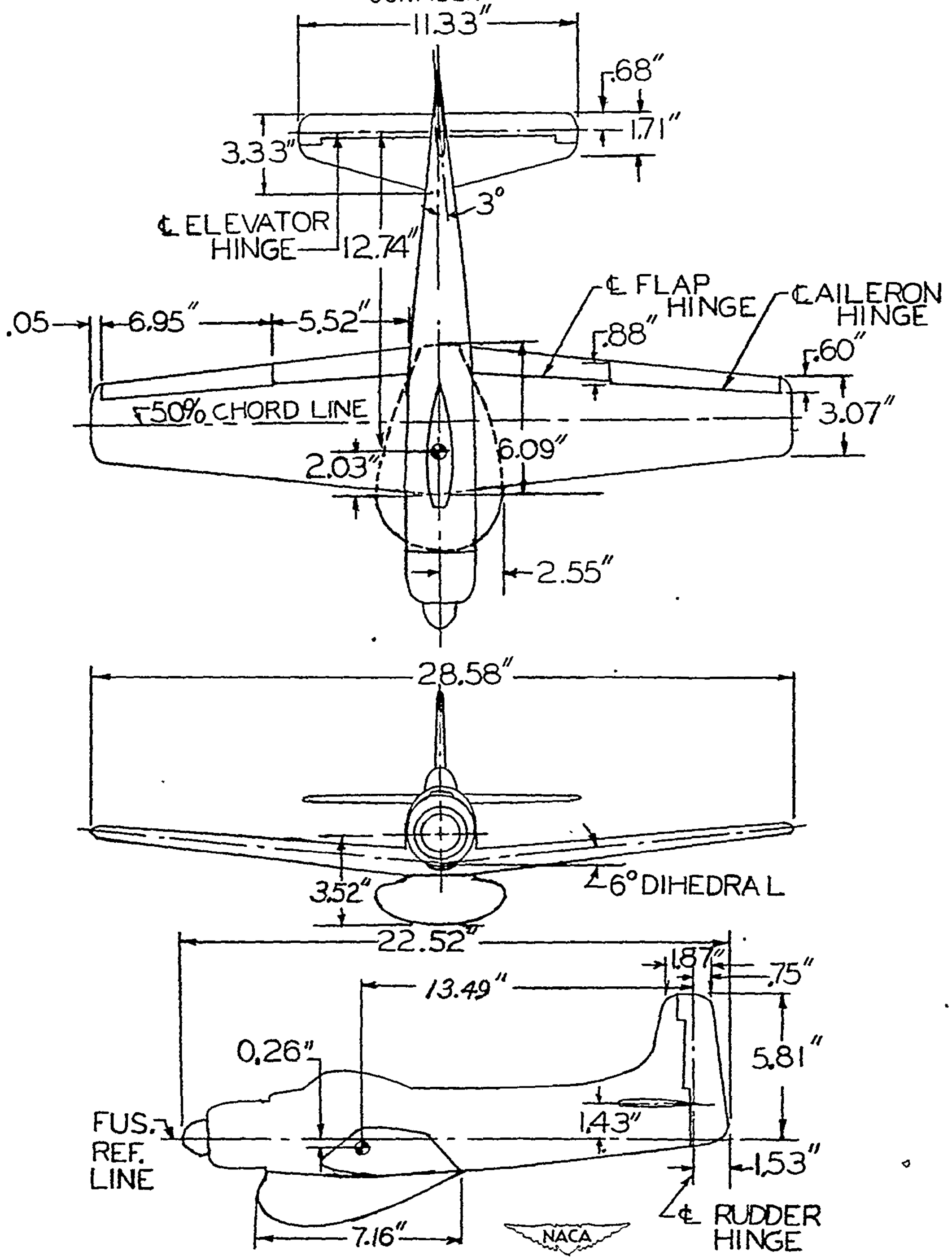

Figure 1.- Three-view drawing of the $\frac{1}{21}$-scale model of the Douglas AD-2W airplane with the center-of-gravity location shown for the normal gross-weight loading.

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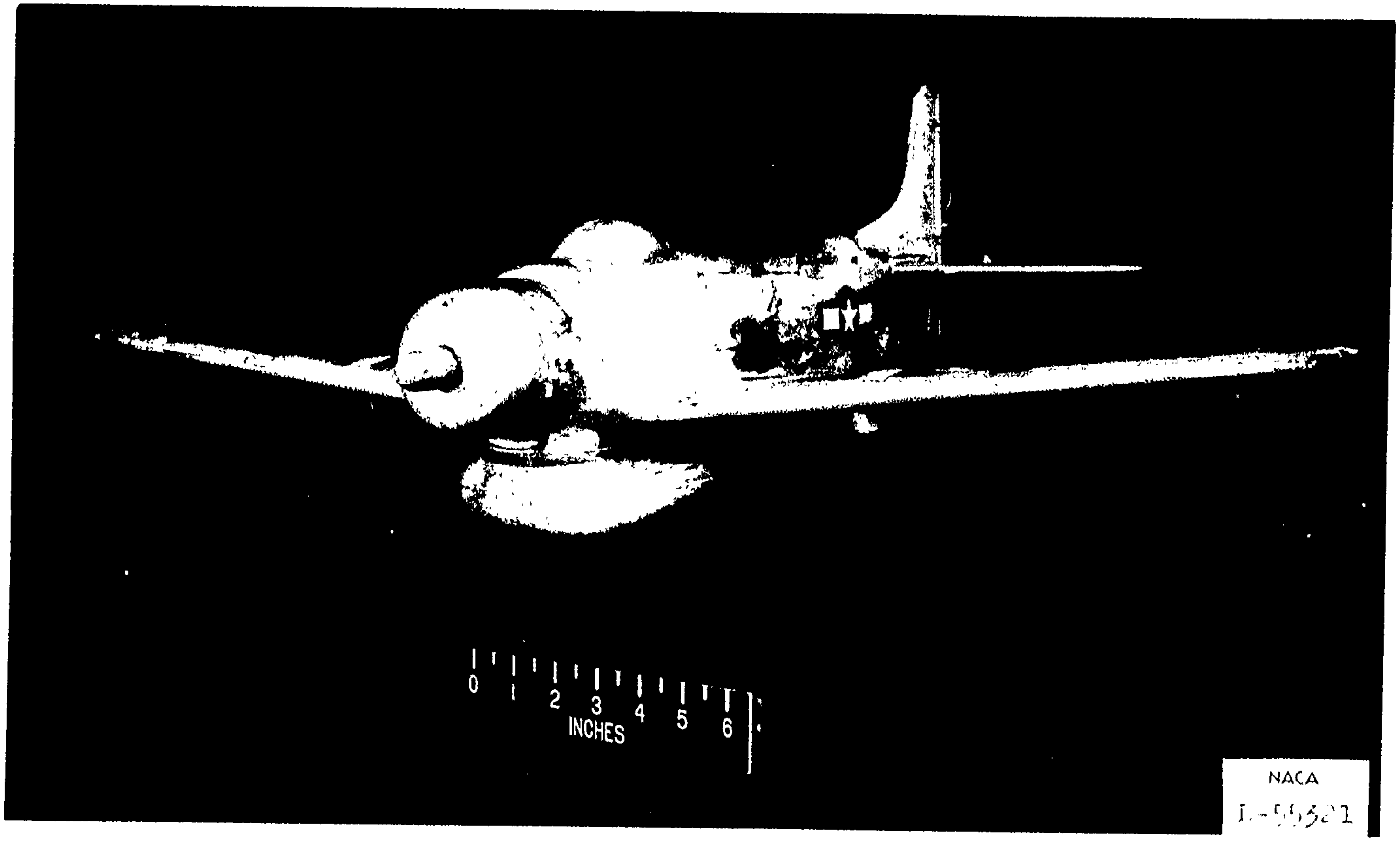

Figure 2.- The $\frac{1}{21}$-scale model of the Douglas AD-2W airplane as tested in the Langley 20-foot free-spinning tunnel.

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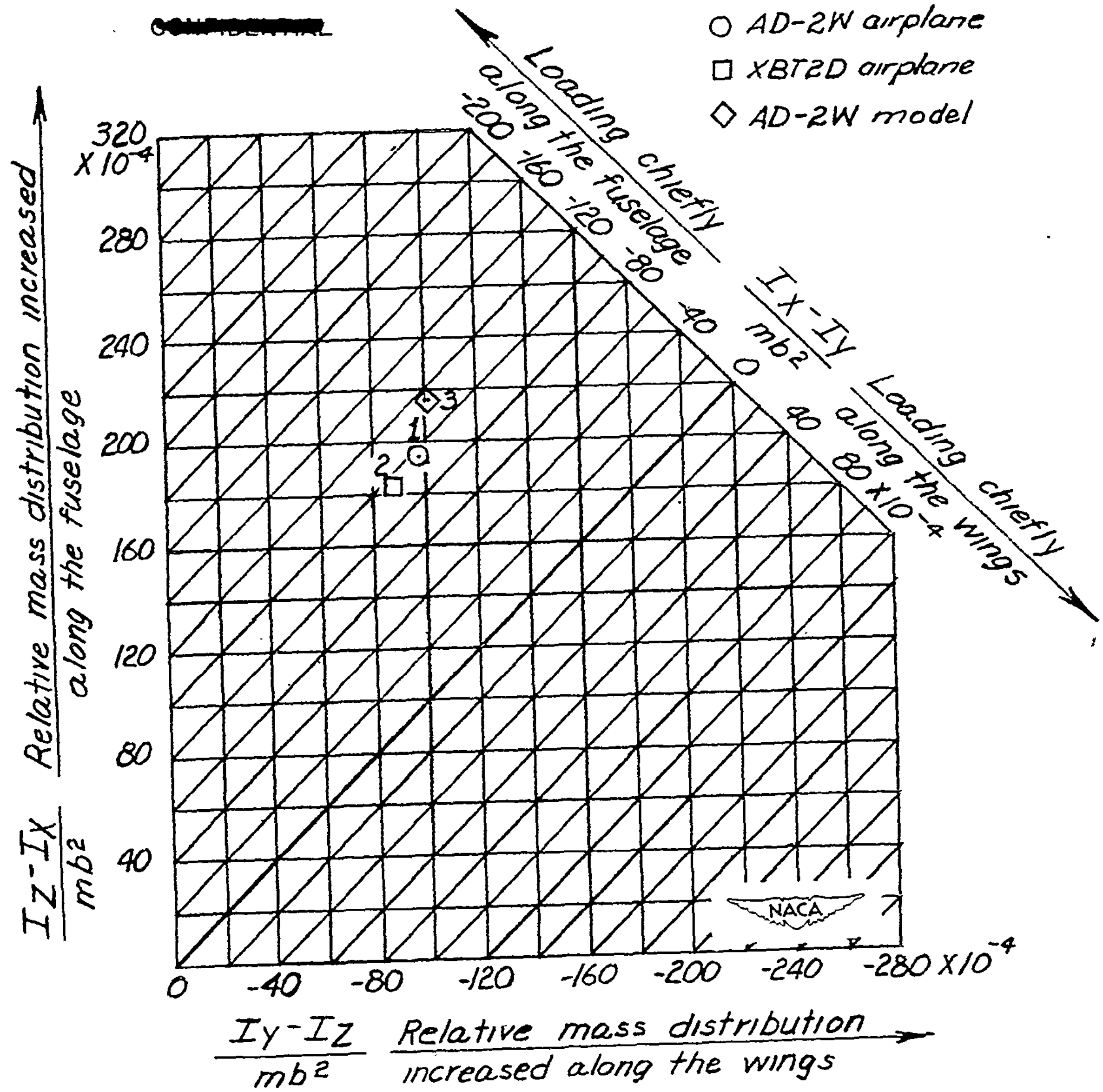

Figure 3.- Mass parameter for the normal gross-weight loading tested on the AD-2W model and for corresponding loading of the airplane and for the normal loading of the XBT2D-1 airplane. (Points are for loadings listed on table II.)

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